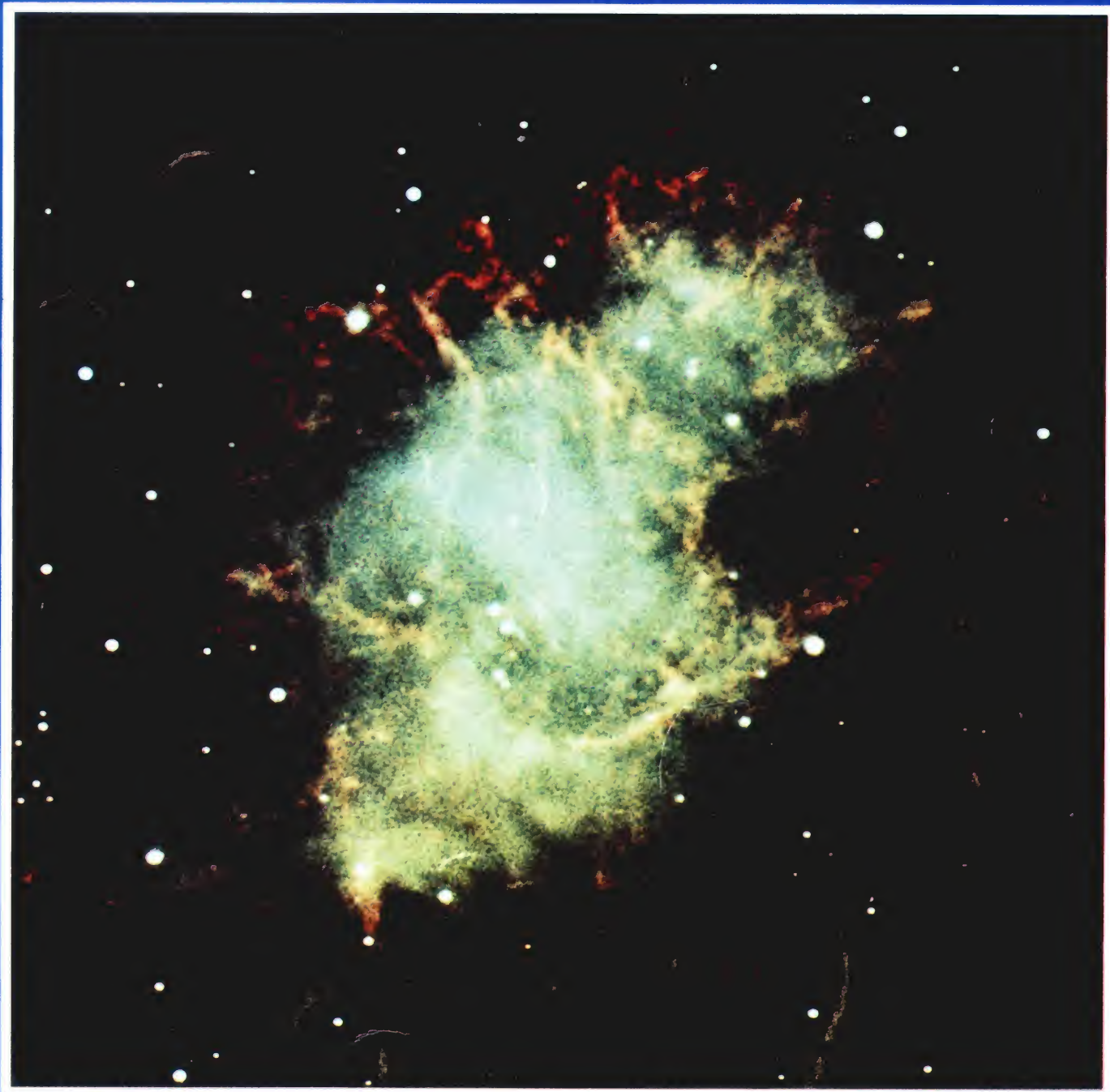


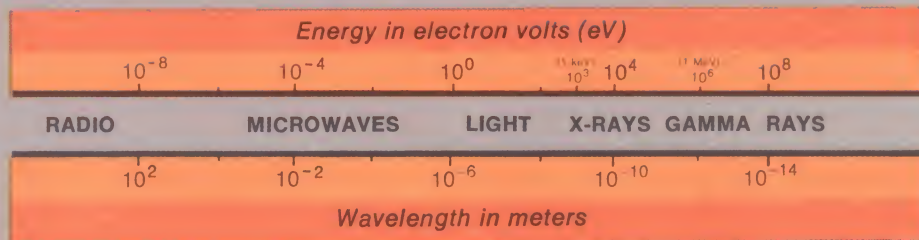
Quasars, Pulsars, Black Holes...and HEAO's





"This Fool wants to turn the Whole Art of Astronomy Upside Down."

Martin Luther on Copernicus




THE ELECTROMAGNETIC SPECTRUM. Radiation at any point on this spectrum moves in a vacuum at the speed of light: 186,000 miles per second. X-rays and gamma rays are no different from visible, TV, or radio radiation except for their shorter wavelengths, higher frequencies, and higher energies. The shorter the wavelength, the higher the energy.

◀ **COVER:** The Crab Nebula was first observed in 1054 A.D. as a supernova, a catastrophic explosion in which a star with a mass several times that of our sun blew up, spitting out a cloud of matter it had been making. The Crab Nebula is one of the richest objects in the sky for today's astronomers. It emits radiation at all wavelengths from radio to X-ray and its total output is equivalent to the power of 100,000 suns. Its core contains a pulsar. In many ways the Crab symbolizes the new discipline of high-energy astronomy.



Foreword

Recent discoveries of startling celestial objects by high-energy astronomy have led to revolutionary new theories about energy, matter, and the origin of the universe. So fundamental are these discoveries that they may well result in major revisions to the entire structure of physics. These celestial bodies, including quasars, pulsars, and stars, are very violent assemblages of matter; deep within their interiors they undergo physical processes so energetic that they cannot be reproduced here on earth. To understand these processes, we must go to the natural laboratory of the universe.



Beginning in 1977, these objects and the universe will be surveyed by a new generation of large X-ray, gamma ray, and cosmic ray instruments carried onboard High-Energy Astronomy Observatories (HEAO). These satellite observatories will explore the invisible, high-energy universe which lies beyond the range of the visible universe explored by such earth-based instruments as the Mount Palomar telescope. HEAO will study the objects described in this booklet. These energetic sources are destined to play an ever greater part in our lives. If they yield the data expected, a new understanding of astronomy and of physics will emerge. This new branch of science is appropriately called astrophysics—the physics of the stars. The ultimate benefits of such new knowledge could range from the development of additional sources of energy to a dramatic change in our view of ourselves and our place in the universe.



ASTRONOMY AT A TURNING POINT

"In 1543, an obscure Polish priest named Nicolaus Copernicus set forth the shocking theory that the earth revolves around the sun. Defying the dogma that because man was created in the image of God, his place must be at the center of the universe, Copernicus unleashed a theological and scientific controversy that was to last more than two centuries."¹ On the 500th anniversary of the birth of Copernicus, a new revolution in astronomy is underway, a revolution perhaps destined to be as far-reaching as that begun by the lowly Polish priest 20 generations ago.

*"In no scientific discipline has there been such an avalanche of surprising discoveries as there has in astronomy over the past decade."*²

—Herbert Friedman

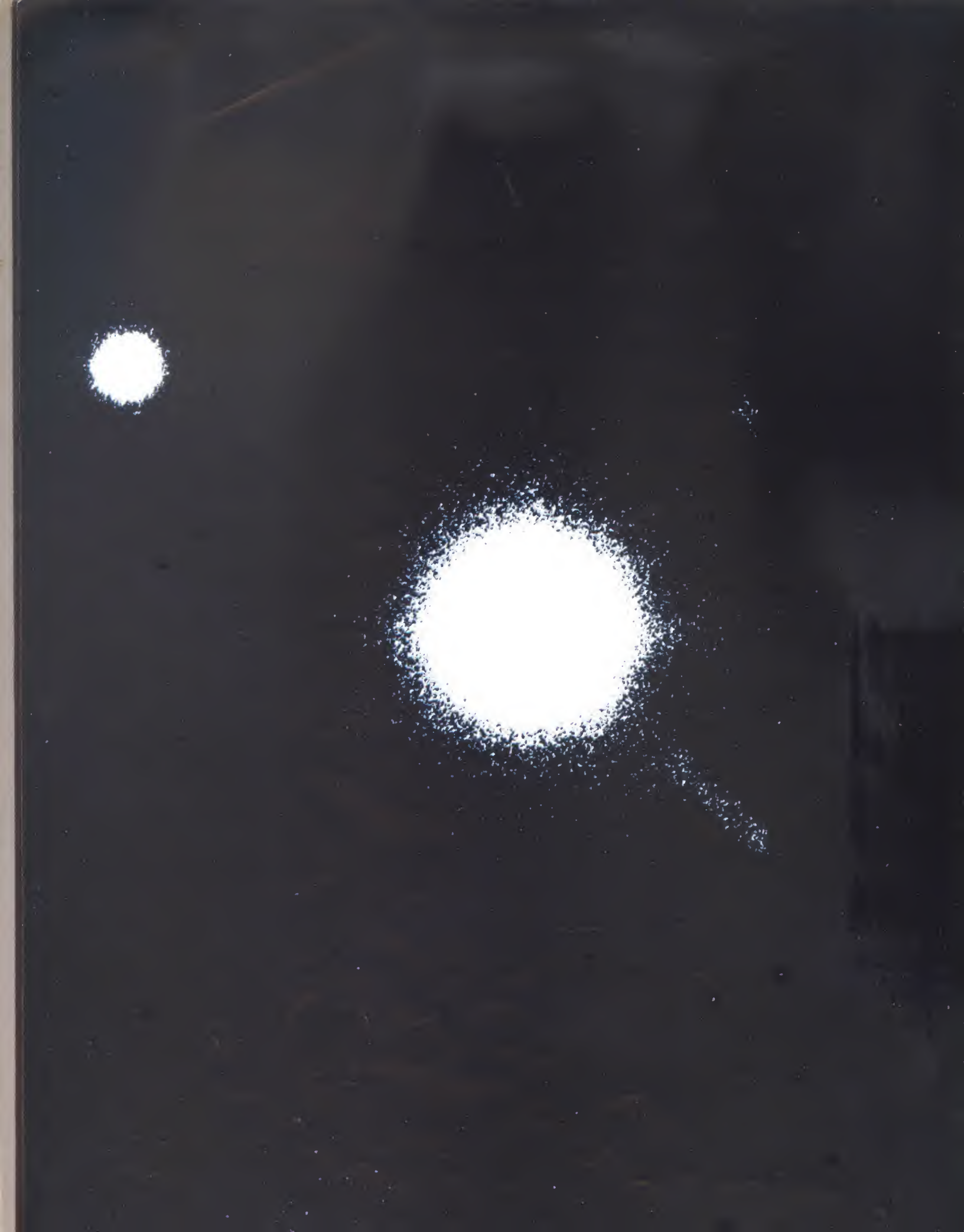
A series of extraordinary observations of new astronomical phenomena made during the last decade are the basis for this revolution. To the classic visible universe, the new astronomy has added a picture of a universe characterized by "a general cosmic violence, exploding galaxies and quasars, an almost universal presence of high-energy particles and magnetic fields, and events suggesting relativistic collapse."³

These discoveries appear to be converging toward a dramatic synthesis of basic ideas about the cosmos. The relativistic universe which Einstein foresaw early in the 20th century is actually being observed today. Ideas and predictions about the universe made only five years ago, which astrophysicists did not expect to see confirmed within their lifetimes, are now being verified by exciting observations.

In these discoveries, we are looking at the life cycles of stars, galaxies, clusters of galaxies, and perhaps the evolution of the universe itself. We are seeing energy processes and aspects of nuclear and high-energy physics never previously observed. Three of the very unusual objects which have been discovered are described here briefly: the quasar, the pulsar, and the black hole.



◀ **GALAXY M 82.** A violently energetic explosion in this galaxy, 10-million light years from earth, has been underway for 1,500,000 years and is still young. A mass of hot hydrogen equivalent to the mass of five-million average stars is bursting out of the galactic nucleus. So great is the force of this explosion that it is shaking up neighboring galaxy M 81, many light years away.



QUASARS

Quasars may be the same size as large stars, yet they emit energy at all wavelengths equivalent to that of a thousand galaxies and produce more energy in a given volume than any other object in the sky. They were first called Quasi-Stellar Objects when discovered in 1963 by radio astronomers because they were point sources of radio

"A healthy quasar each year eats up as much energy as our sun will use in its entire existence."⁴

—Maarten Schmidt

energy—starlike—instead of diffused over large areas of the sky like all previously discovered radio sources. To astronomers, finding a quasar is like finding a flashlight which shines as brightly as all the lights in the entire Los Angeles basin.⁵ Understanding their energy processes could be a key link to new theories on the structure of matter itself.

Quasars are controversial objects because observations do not yet permit conclusive interpretation. They are believed to be receding at enormous velocities—up to 92 percent of the speed of light—because of the huge redshifts of their spectral lines. Objects moving at this speed must be billions of light years distant, near the limits of the observable universe. One newly discovered quasar, OQ 172, is believed to be the most remote recorded object in the universe. Calculated to be 10-billion light years from earth, it started sending out its energy before the sun, the earth, or the moon existed—even as stellar dust. If quasars are that remote from us, they may be among the youngest observed objects and may prove important to cosmological research by revealing what the early universe was like.

◀ **QUASAR 3C 273.** The jet extending some 150,000 light years from the edge of the quasar may have been produced by a galactic explosion. Matter is ejected at velocities up to 60,000 miles per second. Quasars may be the cores of young galaxies.





PULSARS

Formed from the collapsed remnants of supernovae explosions, pulsars are extremely dense, rotating neutron stars with intense magnetic fields.

*"During the collapse... the stellar matter passes from the atomic regime of condensed matter and atomic physics through the nuclear realm... to the still mysterious realms of elementary particles.... In this one collapse, the star sweeps through much of modern physics."*¹⁶

They are believed to generate beams of directional energy which sweep across space like a lighthouse beacon. According to this model, when the beam wipes across earth, it appears as a pulse.

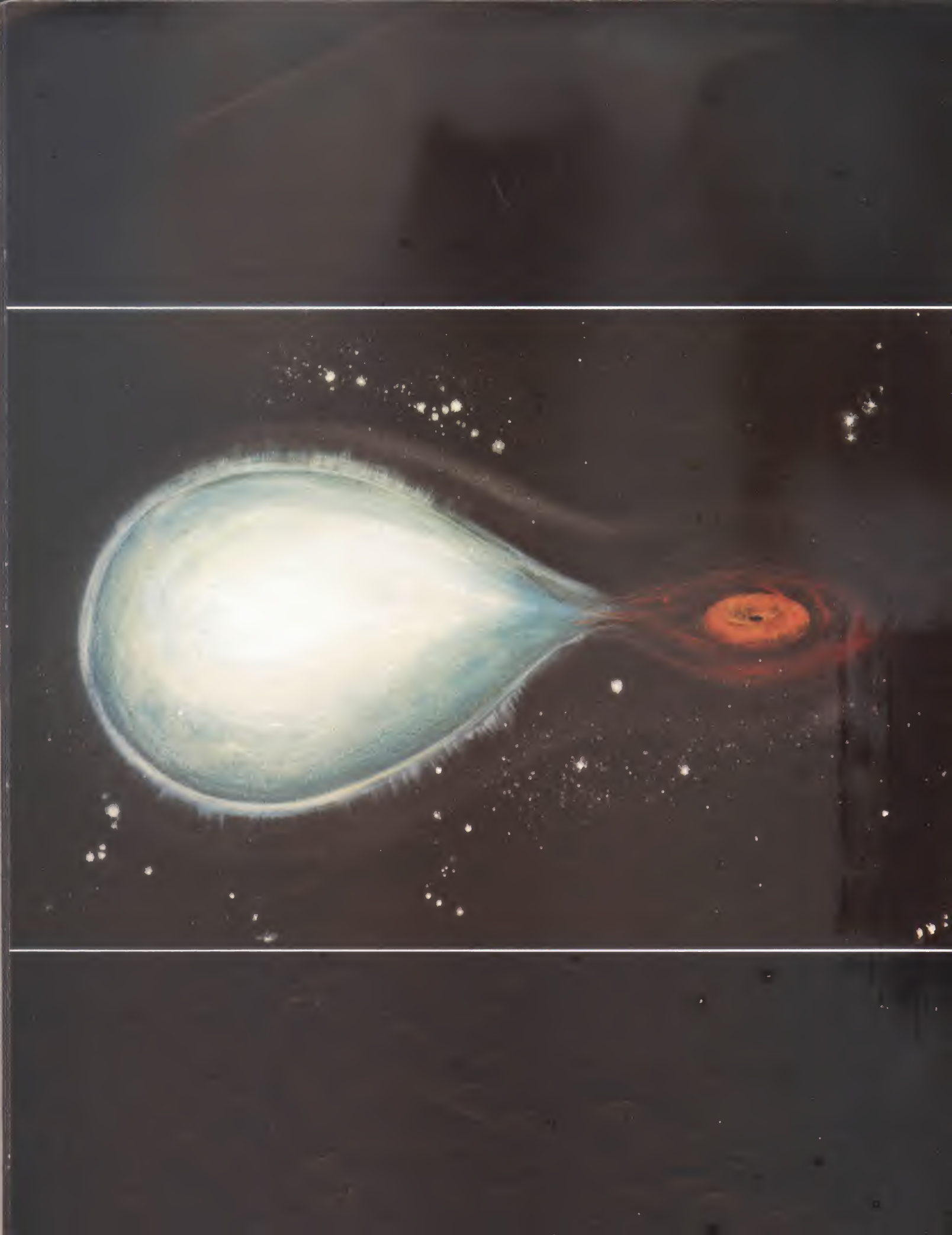
When first formed, pulsars may spin up to 1,000 revolutions per second. Their diameter is typically about 12 miles. When the first pulsar was discovered in 1967, the remarkable regularity of its pulse rate was initially interpreted as a meaningful signal from another intelligent civilization.

A very rich pulsating source for future investigations is Hercules X-1, a binary X-ray star which exhibits a wide variety of pulse periods and interactions with its visible companion. At least one of the pulse periods is produced by eclipses of the X-ray star by this larger companion.

Another important pulsar in the Crab Nebula has been observed in the radio, optical, X-ray, gamma ray, and infrared regions of the spectrum. This spinning star, like the rotor in an electrical power generator, produces most of the Crab Nebula's energy. Collapse to a neutron star converts the gravitational potential energy of the particles in the original star into kinetic energy of explosion and rotation. Squeezed by its collapse, the star explodes, blowing off the matter in its outer shell or mantle. Next, continued collapse spins up the remnant star as it grows smaller. The detailed mechanism of this gravitational collapse is one of the major problems being studied by astrophysicists.



◀ **PULSAR NP 0532.** This pulsar was discovered in the heart of the Crab Nebula shown on the cover. The pulsar is invisible in the top picture. It has flashed on in the bottom picture. Its repetition rate is 30 pulses per second.



BLACK HOLES

Black holes are former stars which, having collapsed to an extremely dense state, have an extraordinarily powerful gravitational field. This field is so strong that no object, light, radio waves, or other radiation can escape to reveal the presence of the black hole.

Black holes may account for 90 percent of the content of our universe. Potentially, there are one-billion black holes in our galaxy. Astrophysicists speculate that black holes may be bridges connecting one part of our universe to another. Similarly, the other violent sources which we have observed may be white holes through which this energy is surging to us.

"At first glance any theory that talks of a hole in space, where time stands still so that a fraction of a second becomes eternity and where all things simply disappear from sight, would seem to belong to the more fantastic realms of science fiction. But to astronomers it is far from fantasy."

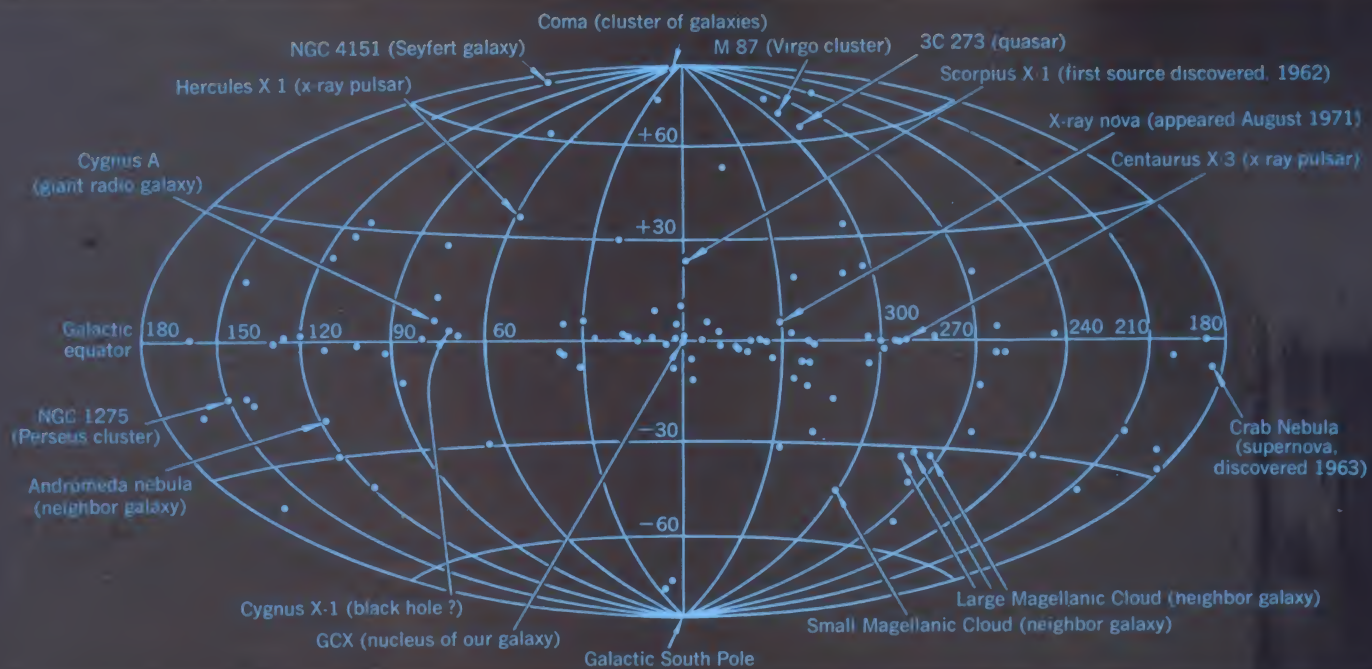
—David Brand

Cygnus X-1, believed to be the first identifiable black hole, was discovered by the Uhuru satellite in 1972. This black hole is the invisible but dominant component of a binary pair of stars and is shown sucking the material of its visible companion into a rotating disk. The black hole is at the center of the disk. The violence of the transfer and shredding action heats the atoms of gas into emitting X-rays at the edge of the black hole. These X-rays indirectly reveal its presence.

The total energy of the particles and radiation near a black hole is enormous. This energy is produced by the conversion of gravitational energy into radiation energy as the matter falls inward, accelerating into the hole. This mechanism is many times more efficient than nuclear fusion, which produces stellar and solar energy. A black hole converts mass to energy more efficiently than any other mechanism known in physics—except for matter-antimatter annihilation. Accordingly, black holes have been called an "ultimate" source of cosmic energy.



◀ **CYGNUS X-1.** This black hole model is based on calculations performed by Kip Thorne of the California Institute of Technology and was painted by Lois Cohen of the Griffith Observatory. Hot, radiating gas glows red as it is accelerated into the black hole.



HIGH-ENERGY ASTRONOMY A KEY TOOL

Many of the most exciting discoveries have been made in a new field called high-energy astrophysics, of which X-ray astronomy is an important part. Astrophysicists study the physics of the stars by observing their X, gamma, and other radiation as well as charged-particle cosmic rays — speeding particles of atomic matter from the sun and sources outside our solar system.

Measurements of this invisible radiation are as meaningful to the high-energy astronomer as visible light is to the classical astronomer. Until the 1950's, except for meteorites, most of what we knew about the universe came to us by light — the astronomer's bridge. Optical astronomy has en-

"They have had a greater influence on astronomy in the first few years than the 200-inch telescope on Mount Palomar did!"⁸

—A scientist, commenting on the immense impact of satellite X-ray astronomy experiments

joyed about 3,000 years of instrumented observation. This optical picture was suddenly expanded by 20 years of radio astronomy, and now, by 10 years of X-ray astronomy—of which only the last few have been conducted from spacecraft.

Although light and radio waves pass through to ground-based instruments, high-energy radiation is absorbed by the atmosphere. Therefore it can only be observed by instruments carried above the atmosphere either by short-lived rockets and balloons or by much longer-life orbiting satellites. Already, X-ray astronomy has discovered well over a hundred new sources in the X-ray sky, largely because of the spectacular success of the small Uhuru X-ray satellite. The larger and heavier satellites of the future such as HEAO will offer much improved observations of this radiation.

The data from high-energy astrophysics provide important additional information about some of the same stellar objects that had been previously observed by optical astronomers. For example, X-ray data yield precise information about orbit size, object diameter, and rotation rates. These data in turn are used by theorists to propose new and improved models of the observed objects and the universe.

In this way, sharing new discoveries and perspectives, astronomers and astrophysicists working in various regions of the electromagnetic spectrum are preparing the basis for the coming synthesis of ideas about the cosmos.



◀ **THE X-RAY SKY.** These high-energy objects have been seen by the Uhuru satellite. Since its launch in December 1970, this satellite has discovered well over a hundred new X-ray sources.



WHERE THIS LEADS US

X, gamma, and cosmic rays streaming to us across the universe contain messages about the structure, composition, and energy processes of the stellar and galactic objects which produced them. "Light from the atomic processes in the stars and galaxies tells us what is going on in their outer atmosphere," says physicist and gamma-ray astronomer Robert Hofstadter. "X-rays tell us what happens deeper within the surfaces and gamma rays will tell us what goes on at even greater depths. The importance of the greater depths of observation can be understood particularly in the recently discovered binary star systems which emit X-rays..." As the matter is transferred between the binary members "perhaps in clouds streaming between the stars, we have a thrilling opportunity to look into this gigantic funnel and see the X-rays and gamma rays arising from the fundamental atomic,

"Up to the twentieth century, 'reality' was everything humans could touch, smell, see, and hear. Since the initial publication of the chart of the electromagnetic spectrum... humans have learned that what they can touch, smell, see, and hear is less than one-millionth of reality. Ninety-nine percent of all that is going to affect our tomorrow is being developed by humans using instruments and working in ranges of reality that are nonhumanly sensible."⁹

—R. Buckminster Fuller



◀ **ROSETTE NEBULA.** The creation of new stars is believed to be underway in such regions as this bubble 100 light-years in diameter. The luminous glow comes from clouds of hydrogen atoms heated by the absorption of radiation from hot, young stars embedded deep in the clouds. This local spectacle is dwarfed by the primeval fireball, which, according to the big-bang cosmology, created the cosmos when a hot, ultradense droplet containing all the matter and radiation in the universe exploded more than 10-billion years ago.

nuclear, and elementary particle reactions occurring in that enormously hot region. The more energetic the quanta [of radiation] we measure, the deeper we can observe, and thereby we can observe the most fundamental processes of nature in action. This is a wonderfully exciting thing to contemplate..."¹⁰

The time is ripe for research based upon high-energy astronomy observations to yield a revolutionary new understanding of physics, relativity, and cosmology. The physics of stars provides a new insight into states of matter and energy processes. Einstein's general relativity field equations are being tested and observed by high-energy observations. And we may be very close to determining if the universe is a steady-state cosmos or if it originated in a hot big-bang or even, possibly, a cold big-bang.



U LTIMATE BENEFITS

The data gathered by this new astronomy may well lead to new theories about energy production and high-density nuclear matter. "In looking to our local energy resources," says physicist Freeman Dyson, "it is well to consider how we fit into the larger scheme of things. Ultimately what we can do here on earth will be limited by the same laws that govern the economy of astronomical energy sources."¹¹ Stars exhibit much more efficient ways of producing energy than the primitive burning which prevails on earth today. Our sun is a small star. Yet one second of its output is equivalent to all the energy ever consumed by men.

In addition to the economic benefits of energy, the cultural benefits of an enlarged consciousness seem likely. This new knowledge of the cosmos might dramatically change our view of ourselves,

"...astronomy ranks with molecular biology in its potential impact on man's philosophical conception of himself and his place in the universe."¹²

—Harvey Brooks



just as men's minds were changed by Copernicus' work. "The revolution in man's view of himself and his place in nature, when he realized that he was not at the center of the universe, but a speck whirled through a gigantic space, was far greater than the mere technical change in astronomy. It brought all things under question. It undermined astrology, and helped man to take a more detached view of himself and nature. It enabled objective sciences of physiology, psychology, and society to be conceived, and medicine to be put on a rational basis. Few men could stomach the revolutionary new view."¹³ An equally dramatic change of consciousness in man's near future cannot be ruled out.

In the mid-19th century when electricity was merely a curiosity, who could have predicted its 20th-century promise of power and electronics? Fifty years ago, who could have foreseen the advent of nuclear energy or believed that experimental and theoretical research in nuclear fission would make it possible to transform the world so swiftly and irrevocably? Similarly, today's astrophysical frontier portends the dawning of the 21st century and perhaps a glimpse of man's cosmic destiny.

◀ **THE BREAKOUT.** The early astronomer in this old woodcut is an emblem of the dawning of cosmic consciousness. His curious mind has left the tidy and familiar green garden of earth behind. Like astronauts poking their helmets above the protective atmosphere into the realm of space, he gazes outward into the unknown, observing the workings of the celestial machinery. He will return from his voyage of the mind to the garden with a clearer perspective and a keener understanding and appreciation of the value of this "blue planet."



HIGH-ENERGY ASTRONOMY OBSERVATORIES [HEAO]

Based on recommendations of the scientific community and the National Academy of Sciences that high-energy astrophysics research should receive very high national priority, the National Aeronautics and Space Administration has undertaken a program called HEAO. To manage this program, NASA named the Marshall Space Flight Center who, in turn, contracted with TRW Systems to design and build observatories into which experiments from leading scientific and educational institutions will be integrated. The first observatory, HEAO-A, will be launched in 1977 to perform a detailed X-ray survey of the celestial sphere. The experiments carried by this mission will study the spectra and measure precise positions and time-variabilities of the X-and gamma radiations from as many objects as possible. These measurements are similar to those made by ground-based telescopes. HEAO-B will

*"These clues have been gained almost entirely with first-generation tools. Future instruments of far greater power are in preparation and the prospects for important advances in knowledge and understanding are immense."*¹⁴

carry a focusing X-ray telescope with a variety of instruments to obtain precise measurements, including X-ray photographs, of the most interesting celestial objects. It is scheduled to be launched in 1978. HEAO-C will be launched in 1979 to perform cosmic ray and gamma ray observations. Follow-on HEAO payloads will be carried by the Space Shuttle.

The initial HEAO observatories will be launched into a 225-nautical-mile orbit from the NASA Kennedy Space Center by Atlas-Centaur boosters. Each 18-foot long observatory will weigh 6,000-7,000 pounds, provide electrical power from solar arrays, and carry over 1½ tons of experiments. The observatory design implements the objectives of NASA to conduct space research at low cost by using a high percentage of off-the-shelf hardware, high safety margins to minimize testing, and a standard spacecraft equipment module to which the experiment complements can be readily attached for each mission. This spacecraft module will also be easily adaptable to many other future missions launched by both Shuttle and conventional boosters.

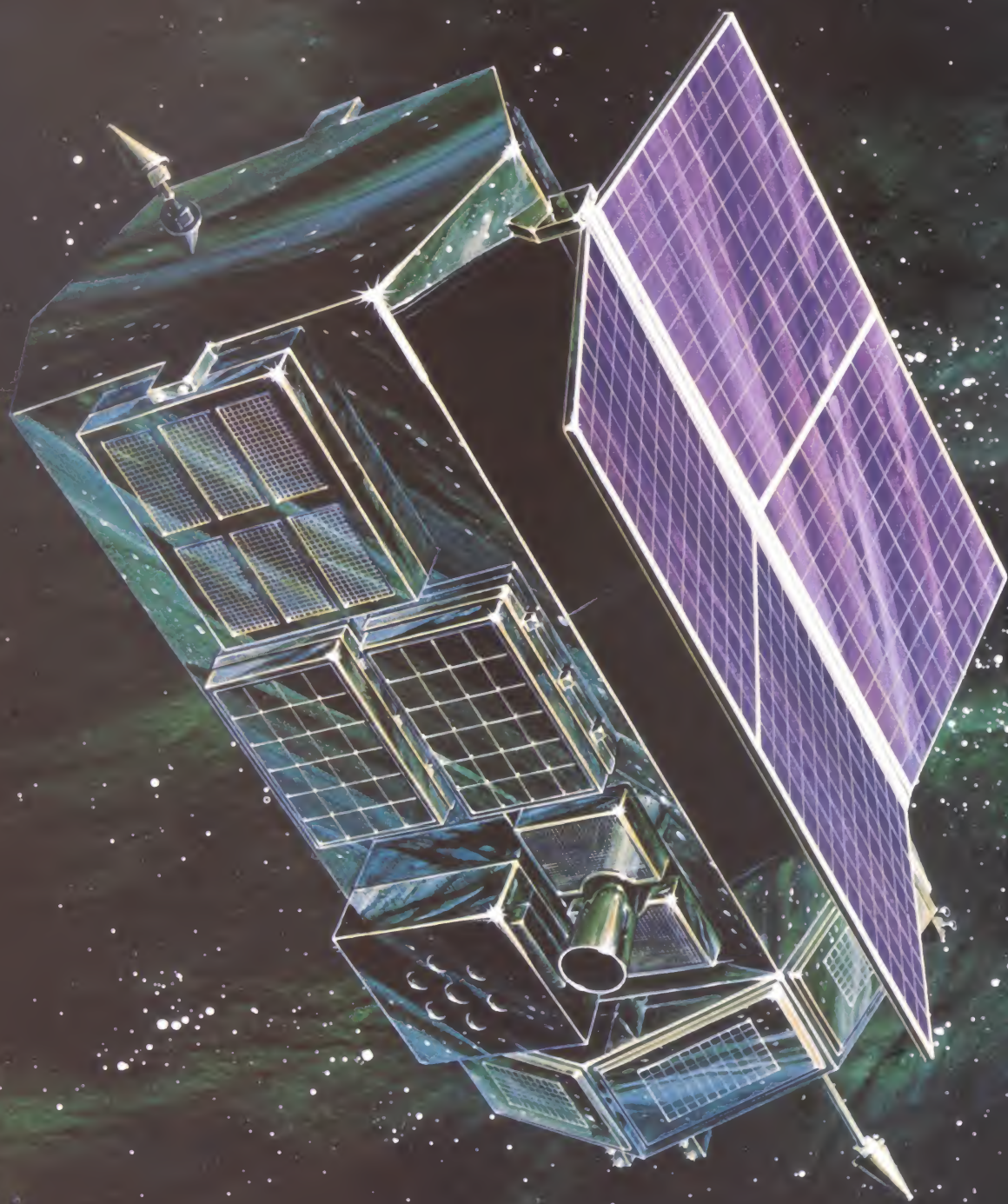
The HEAO observatories will be national scientific facilities dedicated to furthering the understanding of the high-energy universe.

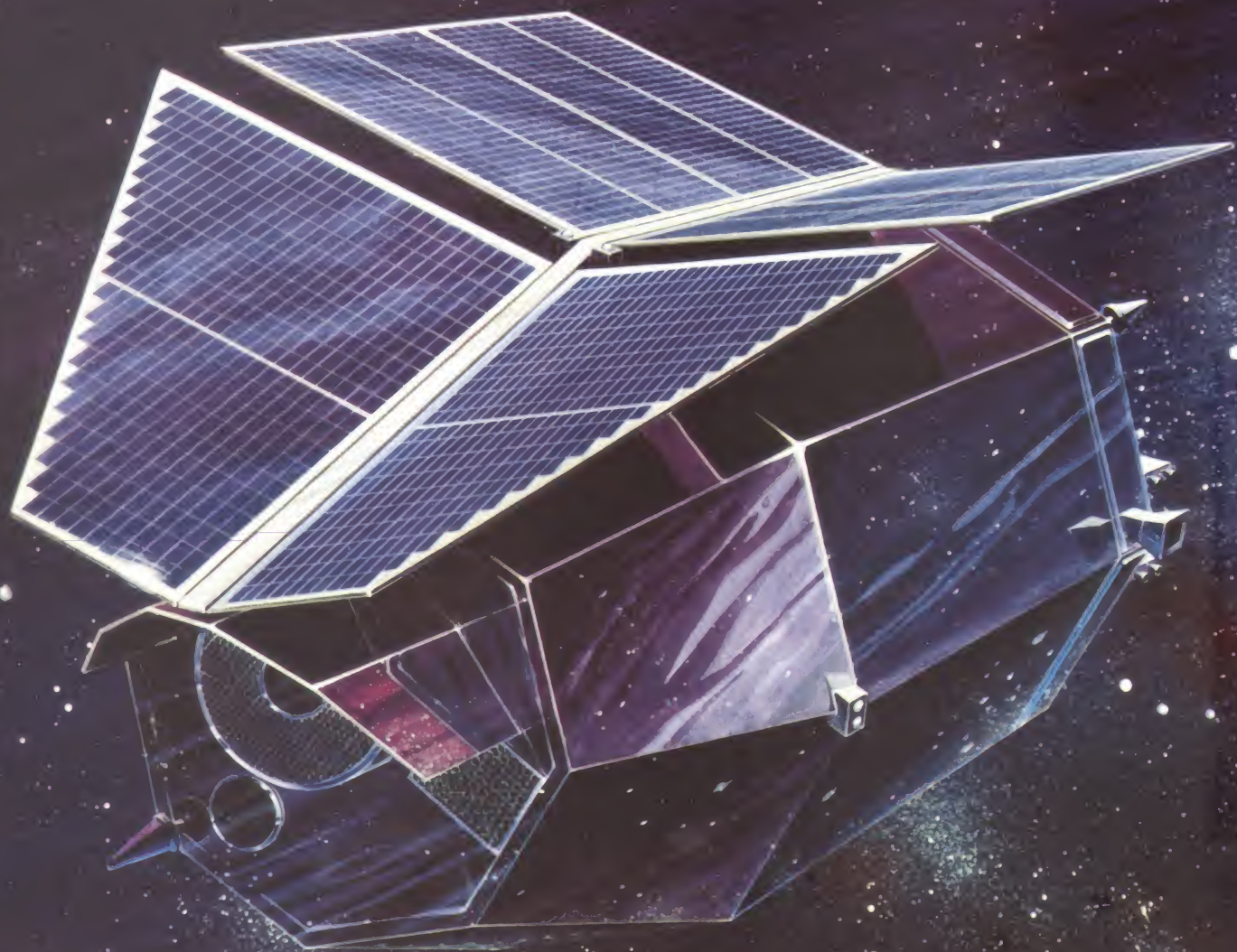


◀ **VEIL NEBULA IN CYGNUS.** Among the celestial objects which HEAO is expected to survey with its large and heavy advanced instruments are such sources as this remnant of the expanded and cooled gas shell from a prehistoric supernova which has evolved much further than the Crab on the cover. In this way, some stars return to space all the matter they have been manufacturing before and during their blow-up. This enriched mixture becomes available to create new stars.

HEAO-A. To be launched in 1977. (Left) ▶

HEAO-B. To be launched in 1978. (Right) ▶

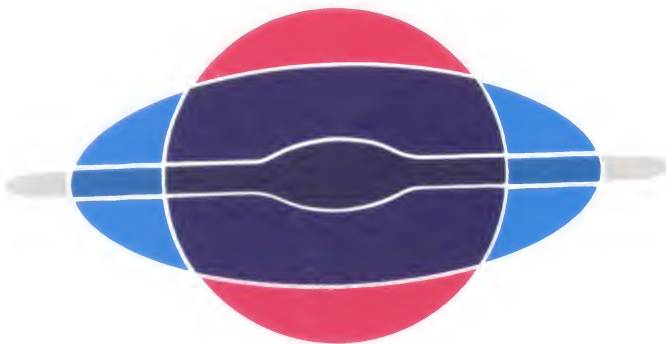




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NOTE: These diagrams appearing on previous pages are the classification of galaxies made by astronomer Edwin Hubble who first discovered other galaxies lying beyond our Milky Way Galaxy only 50 years ago.



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GLOSSARY

BINARY STAR — A pair of stars orbiting about each other under mutual gravitational attraction.

BLACK HOLES — Objects resulting from complete gravitational collapse beyond that of a neutron star. The accompanying gravitational field is so intense that no radiation can escape.

COSMIC-RAYS — High-energy atomic nuclei and electrons originating in stellar sources and interstellar space and observed in the near-earth environment.

COSMOLOGY — The study of the origin, evolution, and structure of the universe.

DIFFUSE BACKGROUND — The microwave radiation that pervades all of space and is believed to be a remnant of the initial big-bang which marked the birth of the universe.

EXPLODING GALAXIES — Violent, energetic explosions centered in certain galactic nuclei where the total mass of ejected material is comparable to 5-million average stars. Jets of gas 1000 light-years long are typical.

GALAXY — A large system of stars held together by mutual gravitational attraction.

GAMMA-RAY — Electromagnetic radiation with energies in excess of 100,000 electron volts.

GENERAL RELATIVITY — The theory of gravity and the nature of gravitational forces as expounded by Albert Einstein.

NEBULA — A cloudlike, luminous mass of gas and dust.

NEUTRON STARS — Remnants of supernovae explosions. They consist of ultra-dense matter composed almost entirely of neutrons which have been squeezed together by the force of gravity exerted by the collapsing matter.

PULSARS — Believed to be rotating neutron stars. The intensity of their radiation in the electromagnetic spectrum is modulated by the period of rotation. Additional periodicities have also been observed.

QUASARS — Quasi-Stellar Objects. Very controversial. Quasars seem to be the size of large stars, yet they emit energy at all wavelengths comparable to that of a thousand galaxies. Characterized by very large redshifts.

SEYFERT GALAXIES — Unusual spiral galaxies characterized by small, extremely bright nuclei containing one to ten billion stars. They are orders of magnitude brighter in the X-ray than in the visible part of the spectrum.

SUPERNOVA — A catastrophic stellar explosion occurring near the end of a star's life in which the star collapses and explodes, manufacturing the heavy elements which it spews out into space. Visible luminosity may reach 100-million times that of the sun.

X-RAY — Electromagnetic radiation typically in the range of 100 to 100,000 electron volts of energy.

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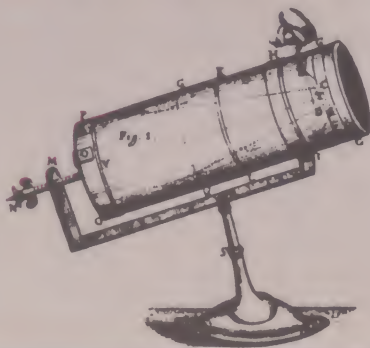
AUTHORS:

- ☐ R. F. Doolittle
- ☐ Ken Moritz
- ☐ R. D. C. Whilden

DESIGNER:

- ☐ R. E. Shepard

PICTURE CREDITS



3C 273 courtesy Hale Observatories.

NP 0532 courtesy Lick Observatory.

The X-ray Sky courtesy Riccardo Giacconi, Smithsonian Observatory.

COLOR PLATES

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Cygnus X-1 painting courtesy William J. Kaufmann, Griffith Observatory.



National Aeronautics and Space Administration
Washington, D.C. 20546

